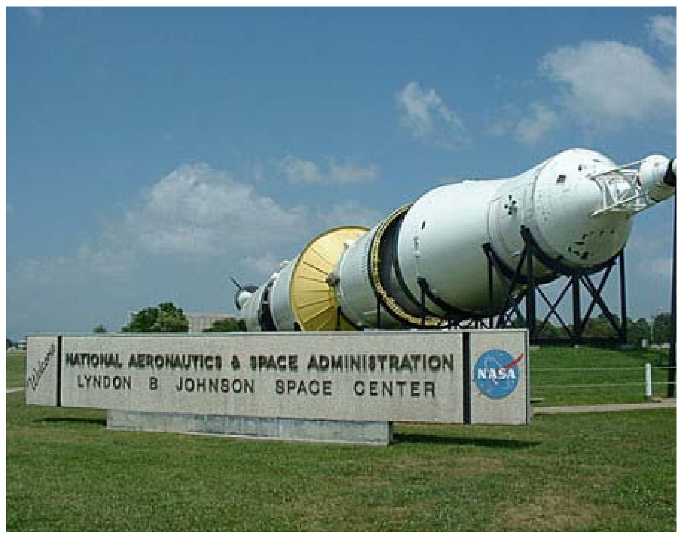
“Image Science and Analysis Group Spacecraft Damage Detection/Characterization”



NASA Lyndon B. Johnson Space Center, Houston, TX
Astromaterials Research and Exploration Sciences (ARES)

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Introduction

The Image Science and Analysis Group (ISAG) is a crucial division of NASA, as the group provides near, real-time imagery analysis of spacecraft flight to assess vehicle performance, debris shedding, and anomalies in support of the Space Shuttle, the International Space Station, the Hubble Space Telescope, and other NASA programs. The prime functions of ISAG include quantitative 2D and 3D measurements, qualitative image interpretation to identify damage, discoloration, deposition, debris, etc., imagery acquisition planning and procedure development, and post-mission engineering analysis. Much of these functions are aimed toward the goal of astronaut safety during missions and the prevention of potential accidents in the future.

Abstract

This project consisted of several tasks that could be served by an intern to assist the ISAG in detecting damage to spacecrafts during missions. First, this project focused on supporting the Micrometeoroid Orbital Debris (MMOD) damage detection and assessment for the Hubble Space Telescope (HST) using imagery from the last two HST Shuttle servicing missions. In this project, we used coordinates of two windows on the Shuttle Aft flight deck from where images were taken and the coordinates of three ID points in order to calculate the distance from each window to the three points. Then, using the specifications from the camera used, we calculated the image scale in pixels per inch for planes parallel to and planes in the z-direction to the image plane (shown in Table 1). This will help in the future for calculating measurements of objects in the images. Next, tabulation and statistical analysis were conducted for screening results (shown in Table 2) of imagery with Orion Thermal Protection System (TPS) damage. Using the Microsoft Excel CRITBINOM function and Goal Seek, the probabilities of detection of damage to different shuttle tiles were calculated as shown in Table 3. Using developed measuring tools,

volume and area measurements will be created from 3D models of Orion TPS damage. Last, mathematical expertise was provided to the Photogrammetry Team. These mathematical tasks consisted of developing elegant image space error equations for observations along 3D lines, circles, planes, etc. and checking proofs for minimal sets of sufficient multi-linear constraints. Some of the processes and resulting equations are displayed in Figure 1.

Goals and Purposes

This array of assignments not only provides an intern with a broad exposure to imagery sciences, but also helps advance the field of spacecraft damage detection, a field that enhances astronaut safety. ISAG was established after the investigation of the 1986 STS-51L Challenger accident, where photographic data detected but could not prevent the fatal explosion. [The continued existence of ISAG fulfills one of the lessons learned from the accident investigation. Since that time, the ISAG experience and capabilities in the area of image analysis have grown dramatically]. Although the different assignments for this project are all geared toward safety issues, they also serve their own separate purposes for ISAG.

HST Project

This project focuses on using different mathematical and geometrical techniques to create an image scale in pixels per inch for images taken from a shuttle in orbit. Using the direct scaling method, we were able to determine how to scale photographs that are taken and recast the calculations for individual photos.

The importance of this method is that it allows us to assess the orbital debris hits that may occur on the Hubble Space Telescope, which further helps to assess the risks that a spacecraft in orbit would encounter. [Millions of man-made debris and naturally occurring micrometeoroids orbit in and around Earth's space environment. This “space junk” collides with spacecraft and satellites. Collision with these particles can cause serious damage or catastrophic failure to spacecraft or satellites and is a life threatening risk to astronauts conducting extra-vehicular activities in space]. By creating image scales from the photos taken, we can calculate nearly precise measurements of object in photos, including surfaces that appear to have strikes from orbital debris. For example, we would be able to determine the strikes per square foot that occurred on the grapple fixture as shown in Figure 2. This eventually helps us determine how susceptible the spacecrafts are to Micrometeoroid Orbital Debris (MMOD) and create models of the MMOD so that spacecrafts are modeled in a secure manner. These tasks all aid in ensuring that future spacecrafts and astronauts in orbit are all designed to withstand the impacts and to be safe and sound from the possible dangers that loom.

Orion TPS Damage Detection Project

This project focuses on using tabulation and statistical methods of screening results of imagery to obtain and provide estimates for the probability of detection of MMOD strikes that occur to shuttles in orbit. Screeners conducted pre-flight and post-flight analysis of imagery of different shuttle tiles in an effort to detect possible MMOD strikes that occurred during flight. We tabulated the results for the damages detected and not detected, and we used the Microsoft Excel-based function Goal Seek to determine the estimated probability of detection and CRITBINOM for the maximum permissible failures of detection with a 95% confidence level.

This work is done mostly for the candidate sensors for visiting vehicle inspections at the International Space Station. For instance, before its recent return to Earth in late May 2010, the space shuttle Atlantis performed a “late routine inspection of the orbiter’s thermal protection system tiles and reinforced carbon-carbon surfaces, including the wing leading edges and nose caps. The inspection is to ensure Atlantis was not damaged by micrometeoroids while docked to the station." Furthermore, these inspections make sure that spacecrafts that leave Earth's atmosphere are clear to safely re-enter Earth without harming the astronauts on board, as well as without harming people on Earth.

Photogrammetry Project

This project focuses on using many different mathematical and 3D geometrical techniques to develop elegant image space error equations for 3D observations. It uses basic and advance geometric algebra from a photogrammetry perspective, where we are given image line parameters and we want to develop multiple cost functions from 3D entities based from minimum sets of point observations with residuals on every point. Some examples included finding the equation for the point of closest approach on a line parallel to another line, finding the equation of a line where 2 planes intersect, and finding the equation of a point on a circle closets to a given point.

The purpose that this works serves for ISAG is that it provides the mathematical basis for the current development of software that is designed to make 3D measurements from imagery provided to ISAG. This software cannot efficiently be purchased; therefore, we are developing it for ourselves. Currently, the software only includes mathematics and photogrammetry for points and graphs, and we worked to add mathematics and photogrammetry for lines, circles, planes, etc. This software will be highly beneficial to the HST and Orion TPS Damage Detection studies by helping with necessary image measurements that need to be calculated to continue to ensure spacecraft and astronaut safety. Overall, it will be beneficial to the entire ISAG.

Impact on Career Goals

The MUST Internship has had a tremendous impact on my career goals. Receiving my Ph.D. in Mathematics, completing research, and teaching math are my intellectual and career related ambitions. This requires a strong mathematical aptitude, analytical skills, and research skills, and I believe that my internship experience at the NASA Johnson Space Center has helped me develop these skills and others, which are vital to succeed in this field of study. This research experience has groomed me into a curious, diligent worker. I have learned how to effectively work with others and to do individual research while still under supervision, as I learned to search for answers to certain questions. Furthermore, I learned to not be afraid to communicate my ideas and/or listen to the instructions of a supervisor. This quality of being independent, but teachable, is one that is appreciated by most mentors and faculty members of graduate research programs.

Professional mentorship is one of the many pillars of the MUST Program. I can testify that I received excellent mentorship throughout my internship experience. My mentors, both formal and informal, were highly instrumental in communicating and breaking down complex concepts that are typically difficult for most people to comprehend. They were very understanding and always willing to help me with any problem that I had. Moreover, my mentors made me feel comfortable from the start of my internship, as they treated me as though I was a part of the team. They also made sure that I had a complete experience, whereas I would not only do plenty of work, but also have fun and enjoy my time there. They helped to schedule different tours of the facility to see much of the cool things that are done at the Johnson Space Center, in Houston, TX, and anything involving NASA worldwide. I believe that this was the ex-factor in me truly enjoying my internship experience. The excellent mentorship that surrounded me throughout this internship justly influenced my mindset and productivity. I hope to receive this kind of mentorship throughout my future research and career experiences.

Figures, Graphs, and Tables

Figure 1: Shows parts of the calculation done for designated Problem 1 to find the equation of the point of closest approach on a line.

$$\text{Problem 1}: L_0(t_0) = O + m^T \vec{v}_0 t_0 \quad t_0 \in \Re \qquad L(t_L) = P_L + \vec{v}_L t_L \quad t_L \in \Re$$

$$where\ \vec{v}_0 = \begin{bmatrix} x \\ y \\ -f \end{bmatrix} and\ O = \begin{bmatrix} x_0 \\ y_0 \\ z_0 \end{bmatrix}.$$

$$P'_C \equiv point\ of\ closest\ approach\ on\ L_0 \qquad [P'_C - P_C] \bullet m^T \vec{v}_0 = 0$$

$$P_C \equiv point\ of\ closest\ approach\ on\ L \qquad [P'_C - P_C] \bullet \vec{v}_L = 0$$

$$\text{After solving for } t_0\ and\ t_L \text{ we obtain}: t_0 = \frac{be - cd}{ac - b^2}, t_L = \frac{ae - bd}{ac - b^2},$$

$$Letting\ a = m^T \vec{v}_0 \bullet m^T \vec{v}_0, b = m^T \vec{v}_0 \bullet \vec{v}_L, c = \vec{v}_L \bullet \vec{v}_L, d = m^T \vec{v}_0 \bullet w_0, and\ e = \vec{v}_L \bullet w_0$$

$$\text{Therefore, } P_C = P_L + \vec{v}_L \left(\frac{ae - bd}{ac - b^2} \right)$$

Table 1: Shows (x,y,z) coordinates for Shuttle Windows and ID points. Also, shows the magnification calculations in pixels per inch, based on the distances and vectors from the windows and ID points, unit vectors above ID points, & angles between the vectors.

182.1493625	**(Pixels per mm)**		
36429.8725	**(Focal Length in Pixels)**		
Window	**X**	**Y**	**Z**
Window 9	576	15.82	483.13
Window 10	576	-15.82	483.13

ID	**X**	**Y**	**Z**
128	1065.59	8.57	500
120	1067.68	-21.81	598.84
87	1083.72	-45.95	754.59
Magnification for 200mm lens in parallel plane (pixels per inch)			
Mag(W9, ID128)	74.35666249		
Mag(W9, ID120)	71.92307043		
Mag(W9, ID87)	62.91441456		
Mag(W10, ID128)	74.27280796		
Mag(W10, ID120)	72.11731015		
Mag(W10, ID87)	63.18900994		
Magnification for 200mm lens in z-direction plane (pixels per inch)			
Mag(W9, ID128)	74.31256912		
Mag(W9, ID120)	70.02119747		
Mag(W9, ID87)	55.57218804		
Mag(W10, ID128)	74.22886363		
Mag(W10, ID120)	70.19984576		
Mag(W10, ID87)	55.74592179		

Table 2: Portion of screening results for TPS study. Green 1 signifies that the screener detected an entry hole and pink 0 signifies that the screener did not detect the entry hole. This was completed for over 30 images.

Detection Results		Tile Color	Entry-hole Measurement		Test Subjects	1-->	Signifies entry hole detected	0-->	Signifies entry hole not detected			
	Damage in FOV			Duval	Farah	Snyder	McBride	Cowardin	Nallard	Vekilov	Varella	Thumm
Image ID												
CB02	**1249S**	b	0.19	1	0	0	1	0	0	0	1	1
	1249L	b	0.27	1	1	1	1	1	1	1	1	1
CB04	**1249S**	b	0.19	0	0	0	0	0	0	0	0	1
	1249L	b	0.27	1	1	1	1	1	1	1	1	1
CB06	**1249S**	b	0.19	1	0	1	1	0	0	0	1	1
	1249L	b	0.27	1	1	1	1	1	1	1	1	1
CB08	**1249S**	b	0.19	0	1	0	1	0	0	0	1	1
	1249L	b	0.27	1	1	1	1	1	1	1	1	1

Table 3: Shows the statistical analysis and calculation for the probability of detection from TPS study.

	Number of trials (given)	Number of successes (given)	Confidence Level (given)	**Estimated PoD - the main goal of this analysis (calculated, not given)**	Max permissible failures - Use CRITBINOM (calculated, not given)	Function to zero-out - Using Goal Seek to zero out ensures that column F result agrees with given number of misses (Column B - Column C) (calculated, not given)
All Screeners (black and white tiles, all damages, 0.19" ≤ Entry Hole Diameter ≤ 0.28	450	391	0.95	**0.83820625**	59	0
All Screeners (black and white tiles, 0.22" ≤ Entry Hole Diameter ≤ 0.28")	333	333	0.95	**0.987151515**	0	0
All Screeners (Black Tiles Only, 0.24" ≤ Entry Hole ≤ 0.27")	135	135	0.95	**0.975285714**	0	0
All Screeners (Black Tiles Only, 0.19" ≤ Entry Hole ≤ 0.27")	252	193	0.95	**0.715665785**	59	0

Figure 2: Grapple fixture, ID 87, which was measured using the pixels per inch calculations in Table 1.